Monte Carlo Transport Codes for use in the Space Radiation Environment

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GEANT4 ("GEometry ANd Tracking")

Available at: http://www.cern.ch/GEANT4

Origin and Usage:

Geant4 [ref G1, ref G2] is a simulation toolkit written in C++ using Object-Oriented principles, and re-engineered from the Fortran-based Geant3. As of Geant 3.21, the Fortran code is officially no longer supported. Geant4 is developed and maintained by a world-wide collaboration including centers at CERN, SLAC, FNAL, KEK and others. The code is available without cost at http://geant4.cern.ch, where a source code browser can also be found.

Because Geant4 is a toolkit, code for a complete executable is not provided. It is the user's responsibility to build the needed geometry from primitives, select the particles and physics processes appropriate to the application, and apply various biasing and scoring options. To aid the user in this task, several so-called "physics lists" are provided which perform the physics selection according to several anticipated use-cases.

Geant4 was originally developed with the needs of the High Energy Physics community in mind and is now used as the primary particle transport code in the ATLAS, CMS, LHCb and ALICE experiments at CERN's Large Hadron Collider (LHC). Since its first uses in the BaBar experiment and the simulation of the Chandra and XMM space telescopes, large user communities in medical and space applications have developed. Geant4 is currently used in NASA-funded studies modeling the effects of single event upsets in semiconductors.

Geometry

An extensive and flexible set of geometry definition tools is provided which allows users to construct complex geometries using Constructed Solid Geometry (CSG), Boundary Represented (BREP) and Tessellated solids. These may be implemented directly in code or imported from file-based descriptions such as GDML and some subsets of CAD/STEP.

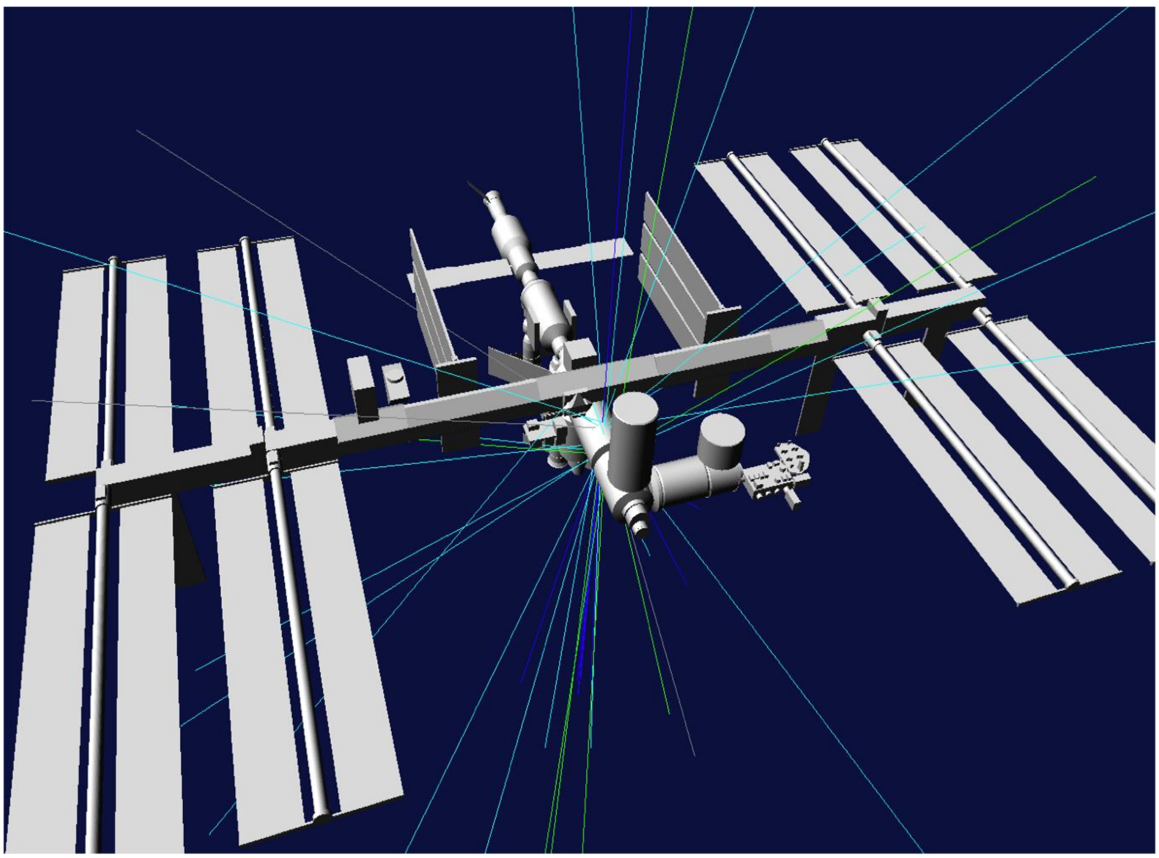
24 CSG solids are provided ranging from simple boxes, spheres and cylinders to extruded solids and generalized twisted trapezoids. Any number of these may be combined to create highly detailed experimental setups. Tessellated solids allow the representation of any shape which may be defined by a set of either triangular or quadrangular facets. Such solids are especially important for the importation of complex shapes from CAD systems.

For certain applications, a 3-D geometry may be parameterized by time, thus enabling detector motion, or for medical applications, patient motion.

Volumes are filled with materials which may be custom-defined by the user down to the isotope level, or with materials defined in the embedded NIST database.

A Geant4 representation of the International Space Station, used for radiation dose studies, is shown in Fig. G1. Detailed internal modeling of the Japanese Experiment Module (JEM) is included.

Figure G1. Geant4 geometry modeling and visualization of the ISS, including tracks from a high energy particle collision.



Physics

Similar to the building of a geometry appropriate to a given experiment, a custom set of physics processes must be assembled by the user and assigned to the appropriate particle types. This is done in a C++ class called the "physics list", and permits the user to choose the specific models and cross sections which implement a physical process. To support this choice, Geant4 provides at least two alternative models and cross section data sets for each physical process. In many cases the choice is between a detailed, yet CPU-intensive model, and a faster, less detailed one.

In other cases one of the available models may work better in some energy and angle regime than another. A brief overview of these alternatives is presented below.

Implicit in the freedom to choose the physics is the potential to mismatch models and cross sections or to omit important physics. For this reason, Geant4 has developed a handful of physics lists, which are recommended for various applications. These physics lists are fully supported and validated so that users may simply choose one of them instead of writing their own.

Several packages of electromagnetic physics processes are offered, each consisting of models and cross sections optimized for a given energy range. The so-called "standard" package covers all energies up to 100 TeV and is typically used in high energy applications. Specialized packages are more precise at lower energies. These include the Livermore models [ref G3] for energies between 250 eV and 1 GeV and the Penelope models [ref G4] for energies between 100 eV and 1 GeV. These are typically used for medical and microdosimetry applications. For very low energies, order eV to 100 MeV, the "DNA" package [ref G5] is available which is used to simulate cell damage and DNA strand breaks.

Common to all of these is a condensed-history multiple Coulomb scattering model, bremsstrahlung, versions of gamma conversion, Compton scattering, photo-electric effect, ionization and Rayleigh scattering. Other processes such as Cerenkov or transition radiation, scintillation or optical, may be absent or present, depending on the physics list.

Geant4 hadronic processes cover projectile energies from several TeV down to sub-thermal. The Quark-Gluon String (QGS) [ref G6] and Fritiof (FTF) [ref G7] models handle hadron-nucleus collisions up to a few TeV. At intermediate energies (10 GeV – 150 MeV), three intranuclear cascade models are available. These are the Bertini-style cascade [ref G8] , the native Binary Cascade [ref G9] , and the INCL++ model [ref G10]. Below 200 MeV there are several precompound and nuclear de-excitation models [ref G11]. Below 20 MeV, two sets of detailed, data-driven models handle neutron scattering, capture and fission. These are the native NeutronHP models [ref G12] , based on the ENDF-B/VII database, and the LEND models [ref G13] based on the Livermore neutron database. These models include thermal line-broadening and do not employ multi-group transport.

Several nucleus-nucleus collision models are available, the most detailed and versatile of which is a QMD model [ref G14]. This model is valid up to about 10 GeV/n and has no restrictions on target or projectile mass, as does the Binary Light Ion Cascade which is based on the Binary Cascade mentioned earlier. An electro-dissociation model and Wilson abrasion/ablation models are also provided. For very high energy nucleus-nucleus collisions, a C++ interface to the Fortran DPMJET 2.5 [ref G15] is available.

All manner of decay processes are offered including the weak and electromagnetic decay of leptons and hadrons and the radioactive decay of isotopes based on the ENSDF database.

Scoring

For space, medical and low background applications, methods to estimate dose and various fluences are required. Geant4 provides several ready-made scorers, handling dose, energy deposit, and current/flux, among others. Filters are also provided which discriminate charge, energy and particle type. These can be invoked directly within the code by assigning them to tracking volumes, or by command line through the user interface. The results of a given score can be written to a file or drawn by the visualization system. Users may also define their own scorers and filters and assign them to the appropriate tracking volumes.

Biasing

For shielding applications or for the study of rare reactions, several biasing options are implemented which may be invoked by the user in the physics list or in the user interface. These include geometric or importance biasing, splitting, cross section biasing and hadronic final state biasing. The radioactive decay process offers many options including branching ratio enhancement, nucleus splitting and directional biasing. Currently, the form and use of these options depend strongly on the process being biased, making their use less than user friendly. A more general, uniform approach is being developed.

Visualization

Geometry and particle tracks may be displayed by one of the eight different visualization packages supported by Geant4. These are: OpenGL, Qt, OpenInventor, DAWN, HepRep, RayTracer, VRML and gMocren. An overview of these is given in the Geant4 Application Developers Guide [ref G16]

Multi-threading

In order to fully utilize modern multi-core shared memory hardware, a multi-threaded version of Geant4 has been developed. The prototype, known as Geant4MT, relies on event-level parallelism similar to ParGeant4 [ref G17] which is built on top of Task-Oriented Parallel C/C++ (TOP-C) [ref G18]. Testing on Westmore and AMD chips has shown excellent scalability when using detailed geometries and the most commonly-used physics lists. The prototype currently runs only in batch mode on Linux platforms, and does not support visualization. By December of 2013, the full-function, official version of Geant4 will be multi-threaded and it is expected that only minimal changes to user code will be required to employ the multi-threading capability.

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